CHAPTER 5

Reliability Evaluation of Renewable Energy Resources

5.1 Introduction

For generation reliability evaluation, a dataset required to calculate LOLP comprises generation characteristics and demand requirements. For conventional unit, the generation capacity and FOR are required, while the generation pattern or profile is also required for the renewable unit.

The modeling of various renewable energy resources is proposed by considering daily generation profile. The FOR of renewable unit can be obtained by using the equivalent forced outage rate (EFOR). Generation reliability is then evaluated under the presence of renewable energy resources. The loss of load probability is used as reliability index.

In this chapter, the modeling of renewable energy resources for evaluating generation reliability evaluation is proposed in Section 5.2 and the modification of reliability modeling is then proposed in Section 5.3.

5.2 Reliability Modeling Evaluation

This approach is simplified to evaluate the generation reliability [Chaiamarit and Nuchprayoon, 2013]. Firstly, load data is required for producing the LDC. Then, generation data of both conventional and renewable units, by means of generation capacity and FOR, are collected to produce the ELDC and compute reliability index. In the absence of FOR information for renewable unit, it is proposed that the EFOR can be a substitute. Using a simplified generation profile in Figure 5.1, the EFOR of renewable energy unit can be computed as shown in (5.1).

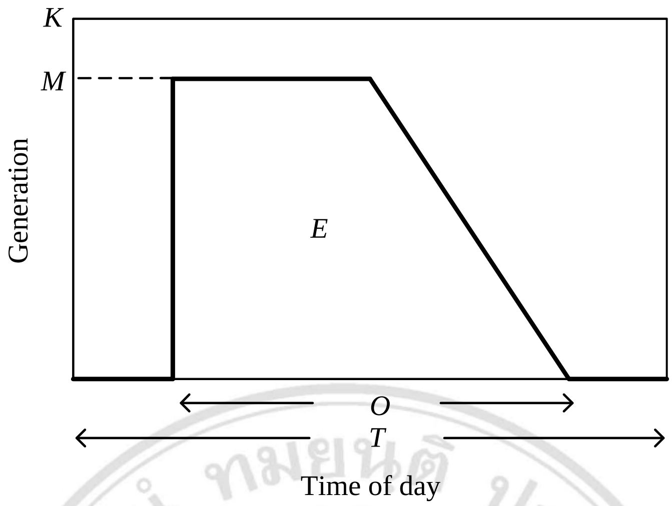


Figure 5.1 Generation profile of a renewable unit.

$$\mathrm{EFOR} = 1 - (E/T)/K = 1 - \mathrm{CF}. \qquad (5.1)$$

where E is an energy generation of the renewable energy unit, T is time horizon (e.g. 24 h/d), K is installed capacity. Note that, in Figure 5.1, the operating duration O of the renewable unit is less than the time horizon and the maximum power M of the renewable unit is also less than the installed capacity. *CF* is capacity (plant) factor.

Next, reliability index is computed in order to determine generation reliability. Finally, the contribution on generation reliability of either conventional unit or renewable unit can be evaluated by using the concept of capacity credit and the effective capacity.

5.3 Modification of Reliability Modeling Evaluation

As mentioned previously, the main variables used to calculate LOLP, are generation capacity and FOR. In case of renewable energy resources, the renewable generation output varies with the time of day which is sometimes not reach the generation capacity as shown in Figure 5.1. Because of this reason, the modification of reliability modeling evaluation is proposed into three approaches to consider the generation capacity and FOR which are used to calculate LOLP. The three approaches are modification of FOR, modification of generation capacity, and modification of both FOR and generation capacity. All approaches are performed under a hypothesis that the LOLP should be different when the generation profile of the renewable unit varies. The generation capacity and FOR are computed based on the generation profile of the renewable unit.

5.3.1 Modification of forced outage rate

In this approach, the generation capacity of the renewable unit remains as its own but the FOR is modified by using EFOR. This approach is simple and easy to calculate the capacity outage probability because it does not change a generation capacity so the outage state is not changed too. The EFOR can be calculated in the period of time based on generation profile [Chaiamarit and Nuchprayoon, 2013]. The EFOR is given as

$$EFOR = 1\text{-}(E/\text{Total Energy}). \tag{5.2}$$

The total energy in (5.2) can be divided into 4 cases as follow:

IA: $$EFOR_{IA} = 1 - \frac{E}{K \times T}. \tag{5.3}$$

IB: $$EFOR_{IB} = 1 - \frac{E}{M \times T}. \tag{5.4}$$

IC: $$EFOR_{IC} = 1 - \frac{E}{K \times O}. \tag{5.5}$$

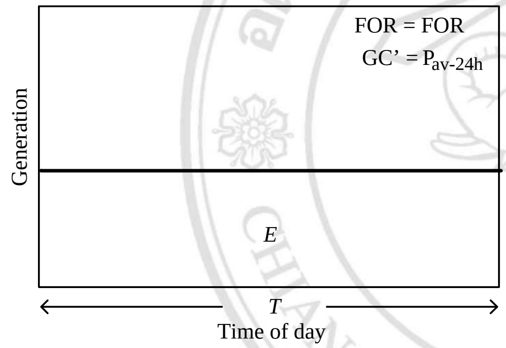
ID: $$EFOR_{ID} = 1 - \frac{E}{M \times O}. \tag{5.6}$$

In case IA, the total energy is defined as the total energy which the renewable unit can produce with the generation capacity in the time horizon. In case IB, the total energy is defined as the total energy which the renewable unit can produce with the maximum capacity in the time horizon. In case IC, the total energy is defined as the total energy which the renewable energy unit can produce with the generation capacity especially in the operation hours. In case ID, the total energy is defined as the total energy which the renewable unit can produce with the maximum capacity in the operation hours.

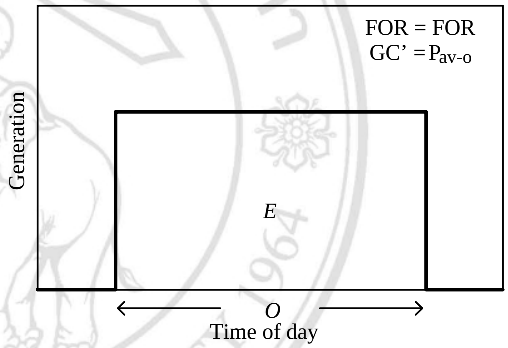
5.3.2 Modification of generation capacity

In this approach, the FOR of the renewable unit remains as its own while the generation capacity of the renewable unit, which is used to calculate LOLP, is modified by using a modified generation capacity (GC’). Although the generation capacity is modified, the energy generation is kept unchanged. Remind that when the generation capacity is changed, the outage state of the capacity outage probability may also be changed.

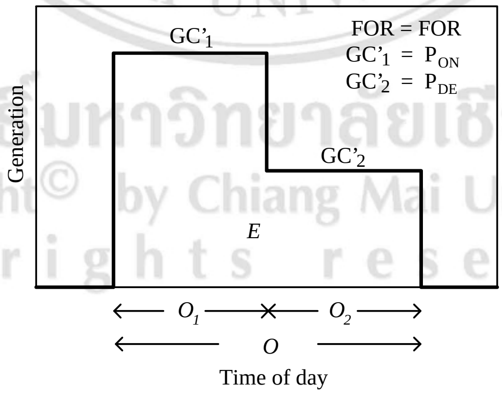
This approach can be divided into three cases which are IIA, IIB and IIC. The illustration of equivalent generation profile of Approach II is shown in Figure 5.2.



(a) Equivalent generation profile of renewable energy unit in case IIA



(b) Equivalent generation profile of renewable energy unit in case IIB



(c) Equivalent generation profile of renewable energy unit in case IIC

Figure 5.2 Illustration of equivalent generation profile of Approach II.

IIA: The actual generation profile of the renewable energy unit is represented as an equivalent generation profile with an average power generation over 24 hours.

Approach IIA proposes that the modified generation capacity is defined as an average power generation over 24 hours ($P_{av\text{-}24h}$) and the FOR remains as its own.

IIB: The actual generation profile of the renewable unit is represented as an equivalent generation profile which is a two-state model. The power generation at ON-state is an average power generation in an operation hour ($P_{av\text{-}o}$).

Approach IIB proposes that the modified generation capacity is defined as an average power generation in an operation hour and the FOR remains as its own.

IIC: The actual generation profile of the renewable unit is represented as an equivalent generation profile which is a three-state model. For the ON-state, power generation is a maximum power. For the de-rated state, power generation is an average power generation in a de-rated hour.

Approach IIC proposes that the modified generation capacity is defined as a maximum power generation at ON-state (P_{ON}) and an average power generation in a de-rated hour at de-rated state (P_{DE}). The FOR remains as its own. The probabilities at ON-state (p'_{ON}), de-rated state (p'_{DE}) and OFF state (p'_{OFF}) are shown in (5.7), (5.8) and (5.9) respectively:

$$p'_{ON} = \left(\frac{O_1}{O_1 + O_2}\right)(1 - FOR), \tag{5.7}$$

$$p'_{DE} = \left(\frac{O_2}{O_1 + O_2}\right)(1 - FOR), \tag{5.8}$$

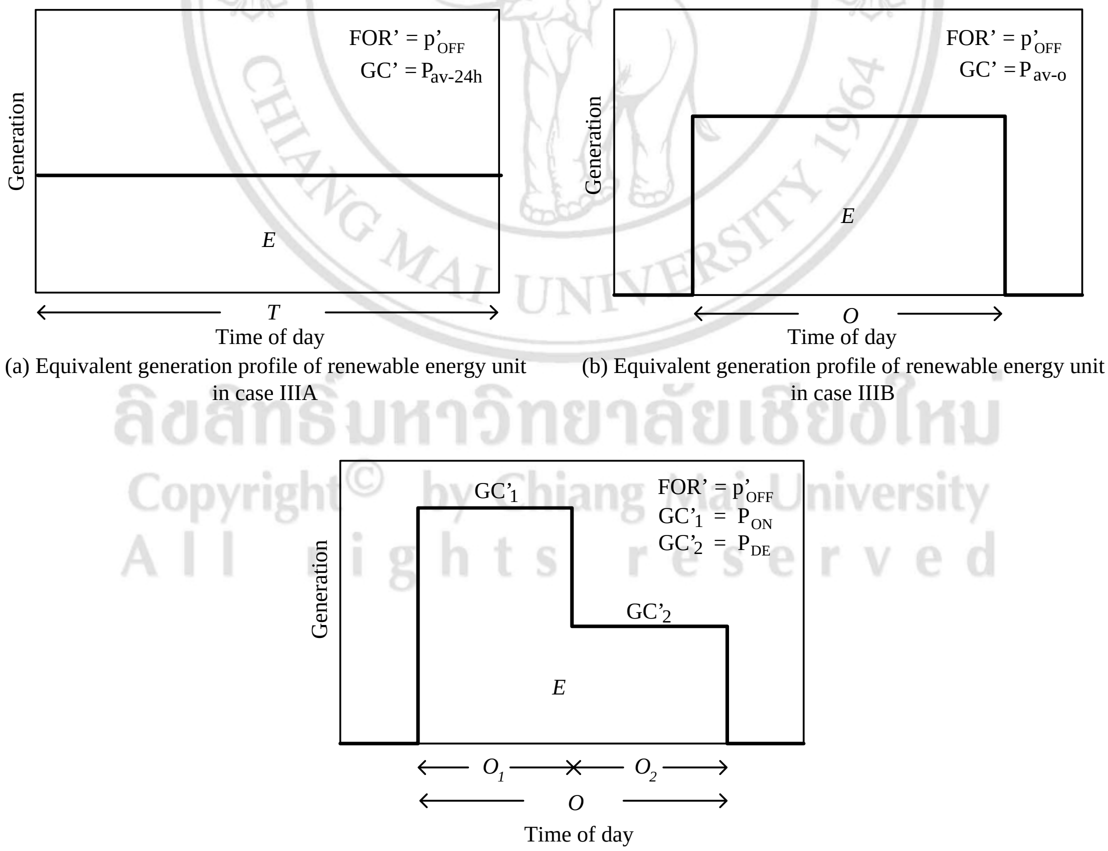
$$p'_{OFF} = FOR\,. \tag{5.9}$$

where p'_{ON} is a probability at ON-state, p'_{DE} is a probability at de-rated state, p'_{OFF} is a probability at OFF-state, O_1 is an operation hour at ON-state and O_2 is an operation hour at de-rated state.

5.3.3 Modification of both forced outage rate and generation capacity

The FOR and generation capacity of the renewable unit are modified as a modified generation capacity (GC') and modified FOR (FOR'). Similar to approach II, although the generation capacity is modified, the energy generation is kept unchanged. Remind that when the generation capacity is changed, the outage state of the capacity outage probability may also be changed.

This approach can be divided into three cases which are IIIA, IIIB and IIIC. The illustration of equivalent generation profile of Approach III is shown in Figure 5.3.



(a) Equivalent generation profile of renewable energy unit in case IIIA

(b) Equivalent generation profile of renewable energy unit in case IIIB

(c) Equivalent generation profile of renewable energy unit in case IIIC

Figure 5.3 Illustration of equivalent generation profile of approach III.

IIIA: The actual generation profile of the renewable energy unit is represented by an equivalent generation profile with an average power generation over 24 hours.

Approach IIIA proposes that the modified generation capacity is defined as an average power generation over 24 hours ($P_{av\text{-}24h}$) and the modified FOR is a probability at OFF state (p'_{OFF}) (in this case, the modified FOR is equal FOR of its own).

IIIB: The actual generation profile of the renewable energy unit is represented as an equivalent generation profile which is two-state unit. The power generation at ON-state is an average power generation in an operation hour ($P_{av\text{-}o}$).

Approach IIIB proposes that the modified generation capacity is defined as an average power generation in an operation hour and the modified FOR is a probability at OFF-state (p'_{OFF}) as shown in (5.10).

$$p'_{OFF} = 1 - \left(\frac{O}{T}\right)(1 - FOR). \tag{5.10}$$

IIIC: The actual generation profile of the renewable energy unit is represented as an equivalent generation profile which is a three-state model with the ON-state power generation is a maximum power generation and the de-rated state power generation is an average power generation in a de-rated hour. The equivalent generation profile in this approach is the most similar with the actual generation profile.

Approach IIIC proposes that the modified generation capacity is defined as a maximum power generation at ON-state (P_{ON}) and an average power generation in a de-rated hour at de-rated state (P_{DE}). The modified FOR is a probability at OFF state. The probabilities at ON state (p'_{ON}), de-rated state (p'_{DE}) and OFF state (p'_{OFF}) are shown in (5.11), (5.12) and (5.13) respectively:

$$p'_{ON} = \left(\frac{O_1}{T}\right)(1 - FOR), \tag{5.11}$$

$$p'_{DE} = \left(\frac{O_2}{T}\right)(1 - FOR), \tag{5.12}$$

$$p'_{OFF} = 1 - p'_{ON} - p'_{DE} . \tag{5.13}$$

5.4 Chapter Summary

Reliability modeling of renewable energy resources is proposed to evaluate generation reliability. The intermittent characteristics of renewable energy unit are considered in the modeling by analyzing its generation profile. The generation capacity and the FOR are the main variables of the reliability modeling.